NGNGV Phase 1 B Gas Plus 0.5g/bhp-hr Project

Presentation to NGNGV Steering Committee 23 July 2003

Powering the Planet - Protecting the Dream

CWI Ultra-low NOx strategy

- Achieving ultra-low NOx levels earlier than diesel vital to CWI business plan
- Full range of technologies available / emerging
- Lean and stoichiometric
  - In-cylinder control
    - Homogenous (LBSI, HCCI), Stratified (HPDI, Prechamber), EGR
  - Post combustion control
    - Oxidation catalysts, Lean NOx adsorber, Lean NOx catalysis, SCR, Three way catalysts, PM filters
- No technology is totally risk-free at present
- Pursue a number of promising technologies to control risk and permit timely ultra-low NOx product development

Project Organization

- CWI is prime contractor to SCAQMD
  - Funding from SCAQMD and CEC
- Majority of project undertaken at Westport
  - Support from Cummins
- EmeraChem is subcontractor to CWI
  - Catalyst test and supply

Ultra Low NOx Lean Burn SI

Phase

1. Apply PLUS technology to B5.9G engine
   - 1.2g/bhp-hr NOx target
2. Demonstrate potential to meet 0.5g/bhp-hr NOx emission over FTP transient cycle
   - By means of exhaust gas aftertreatment
3. Develop strategy for long-term improvements
   - ~0.2g/bhp-hr NOx emission
   - Improved full load performance
   - Increased overall system efficiency

Phase 1 Achievement

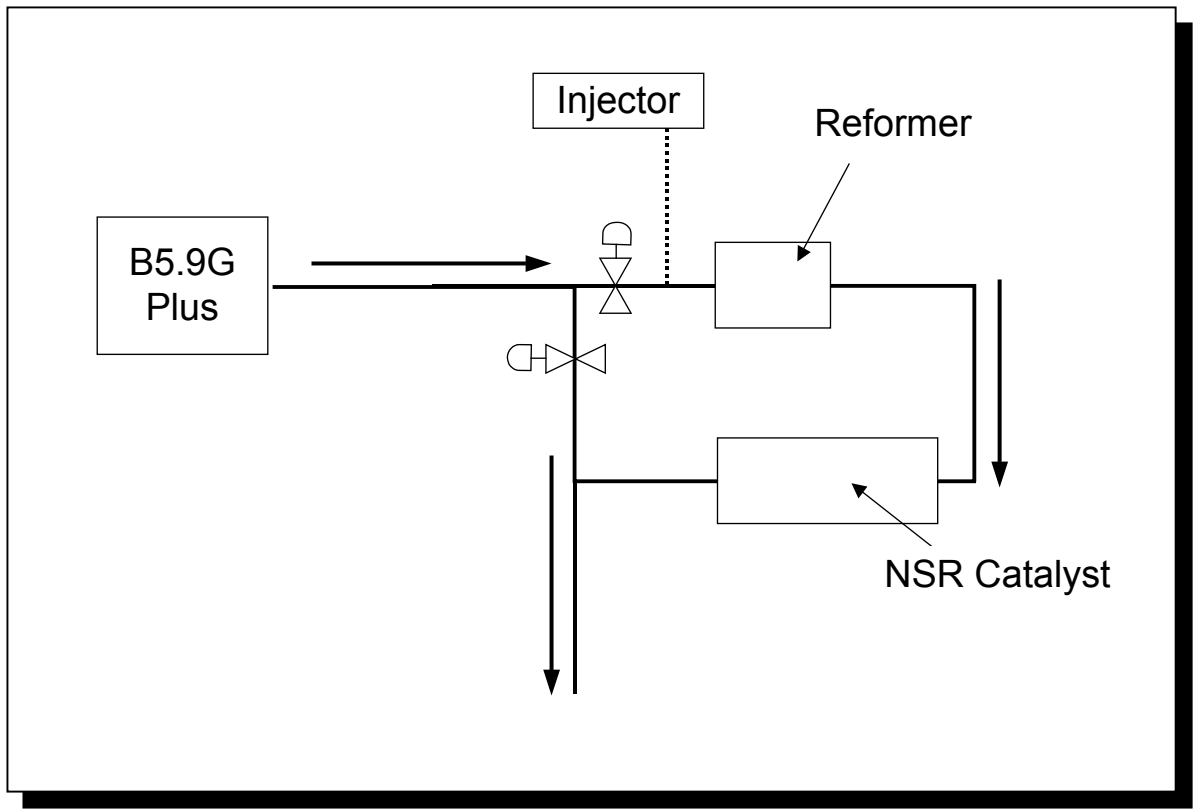
- Phase one of the overall program has been completed
- B Gas Plus product launched
  - NOx+NMHC 1.8g/bhp-hr
  - PM 0.01g/bhp-hr
- Special calibration delivered to Ultra-low NOx project
  - NOx 1.2g/bhp-hr
  - PM 0.01g/bhp-hr
  - THC 5.9g/bhp-hr
  - Approx 4% fuel penalty

Phase 2 Process

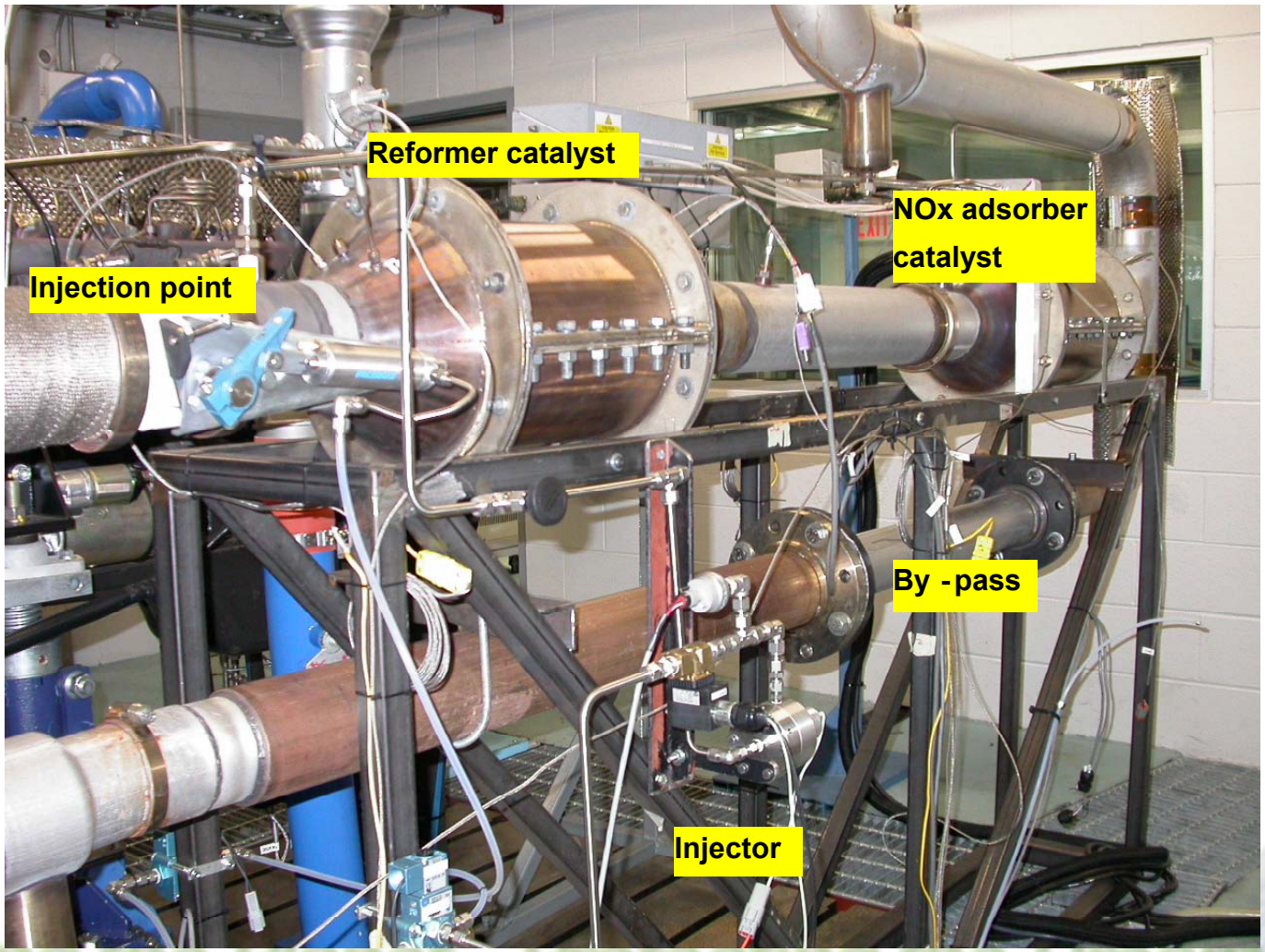
	2002	2003		
	Dec 10	Mar 10	April 10	Sep10
Tasks 1.1-1.7	Design			
Tasks 1.8-1.15		Test		
Tasks 1.16-1.18			Refine	
Tasks 1.19-1.22				Calibrate

Phase 2 - Design

- Single bed NOx Storage and Reduction system
- In-line reformer to generate CO/H2
- By-pass to reduce fuel penalty and size of reformer

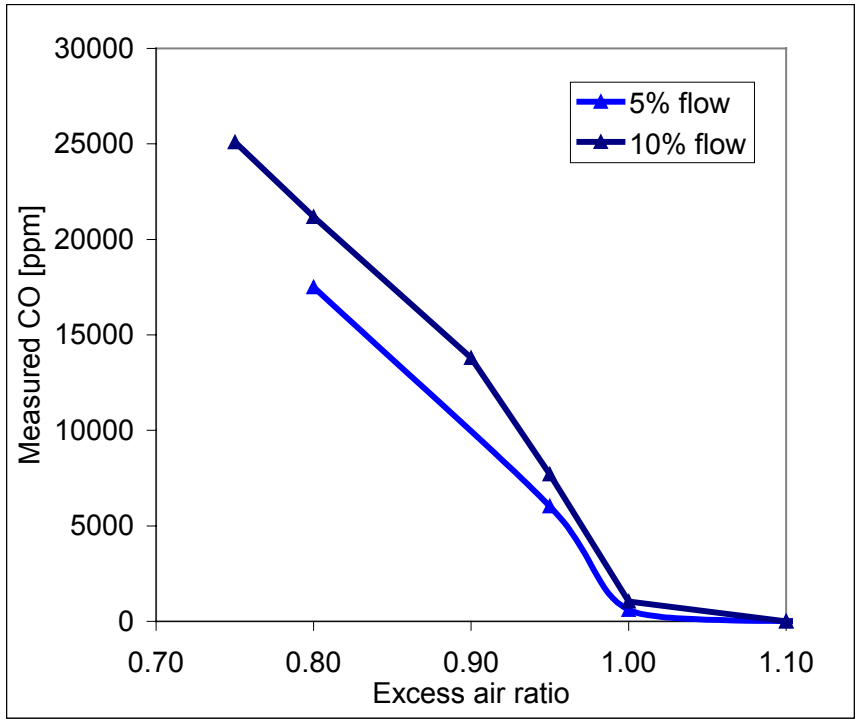


Test Cell Installation

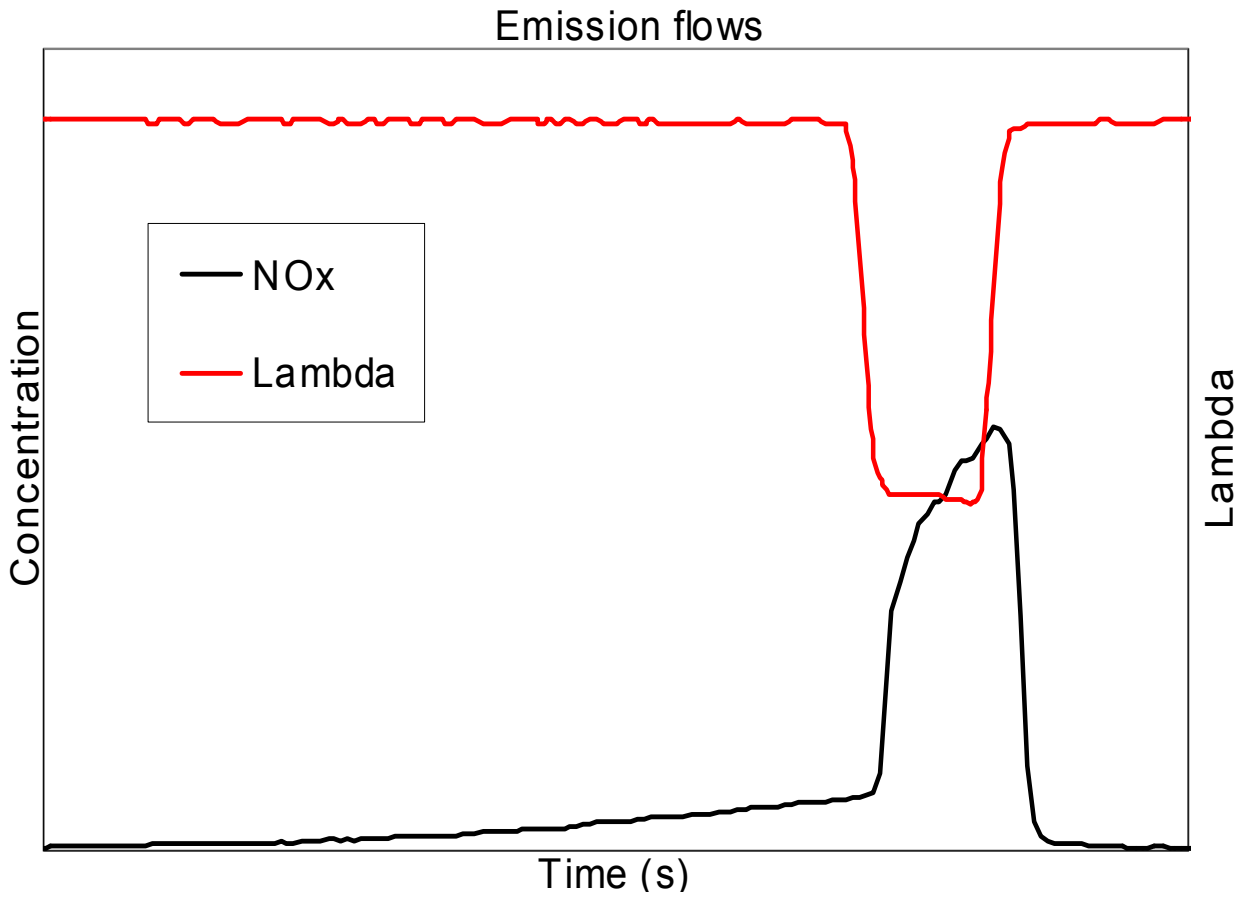


Regeneration Process

- Bypass leg is used to reduce flow over NSR leg
- Natural gas injected to produce rich mixture in partial flow
- “Reformer” catalyst converts NG to CO and H2
- CO and H2 regenerate NSR catalyst

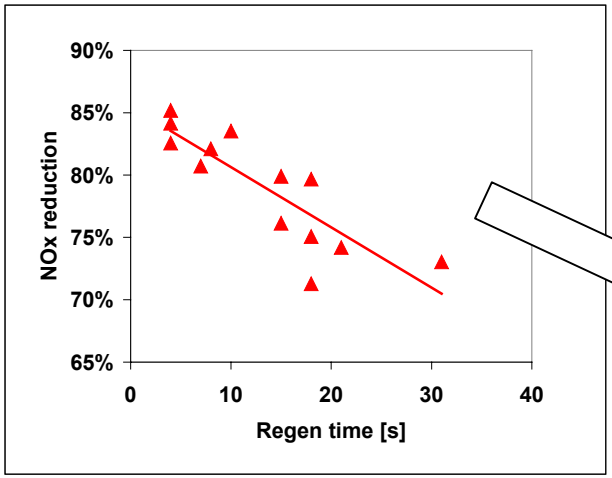


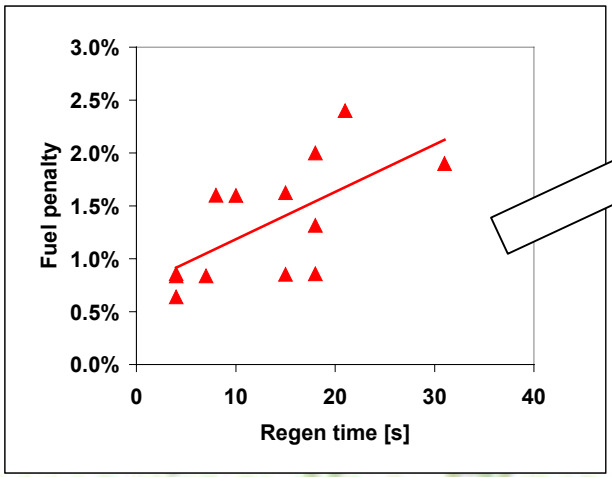
Sample Regeneration

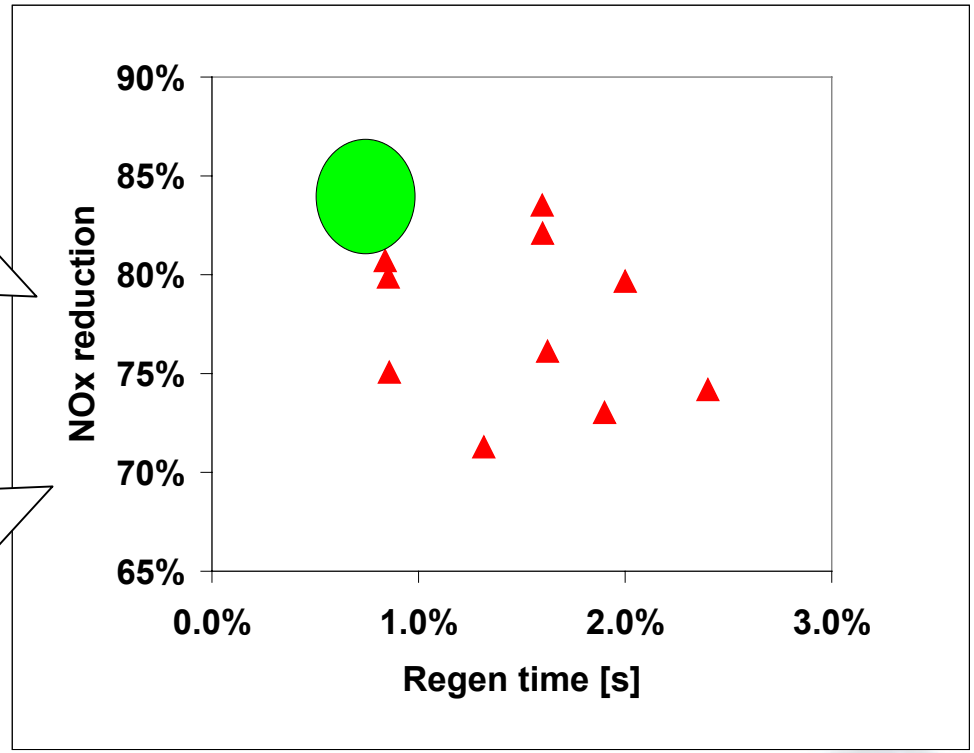


NOx Reduction Versus Fuel Penalty

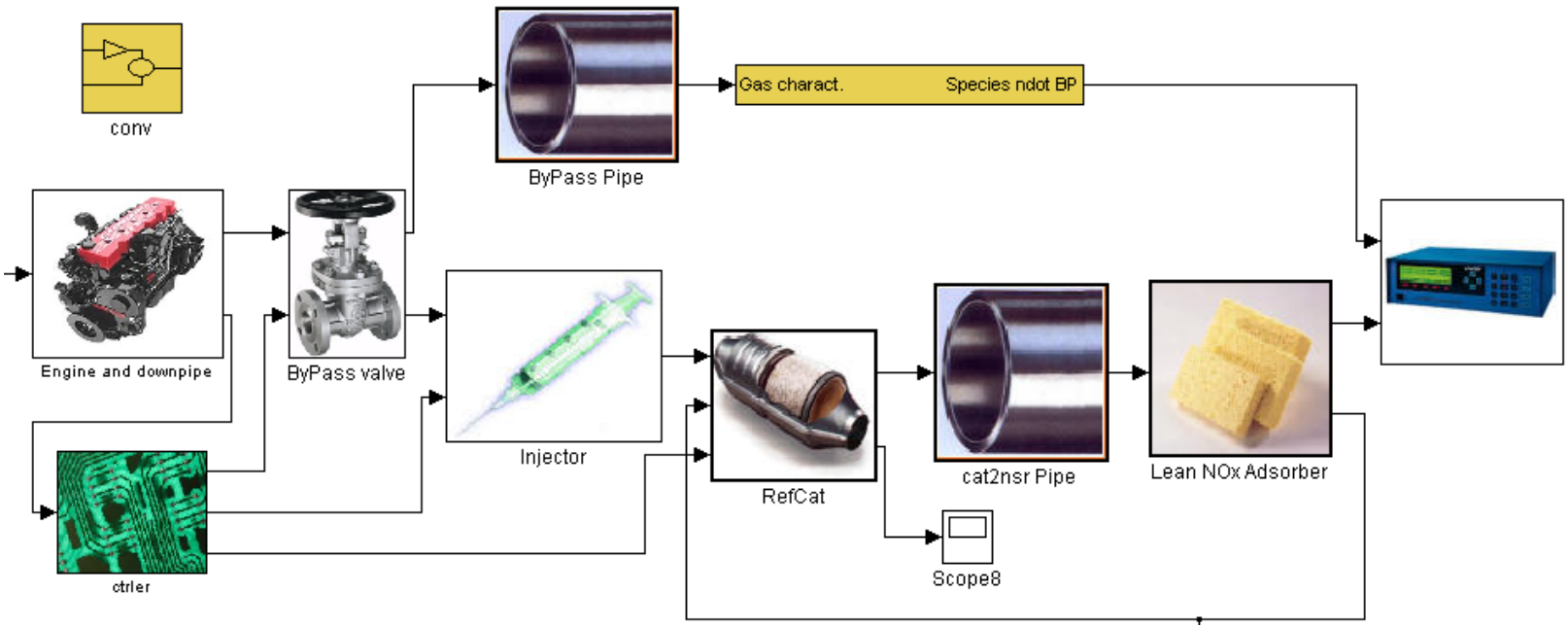
ESC Mode 4 (B Speed, 50% Load)



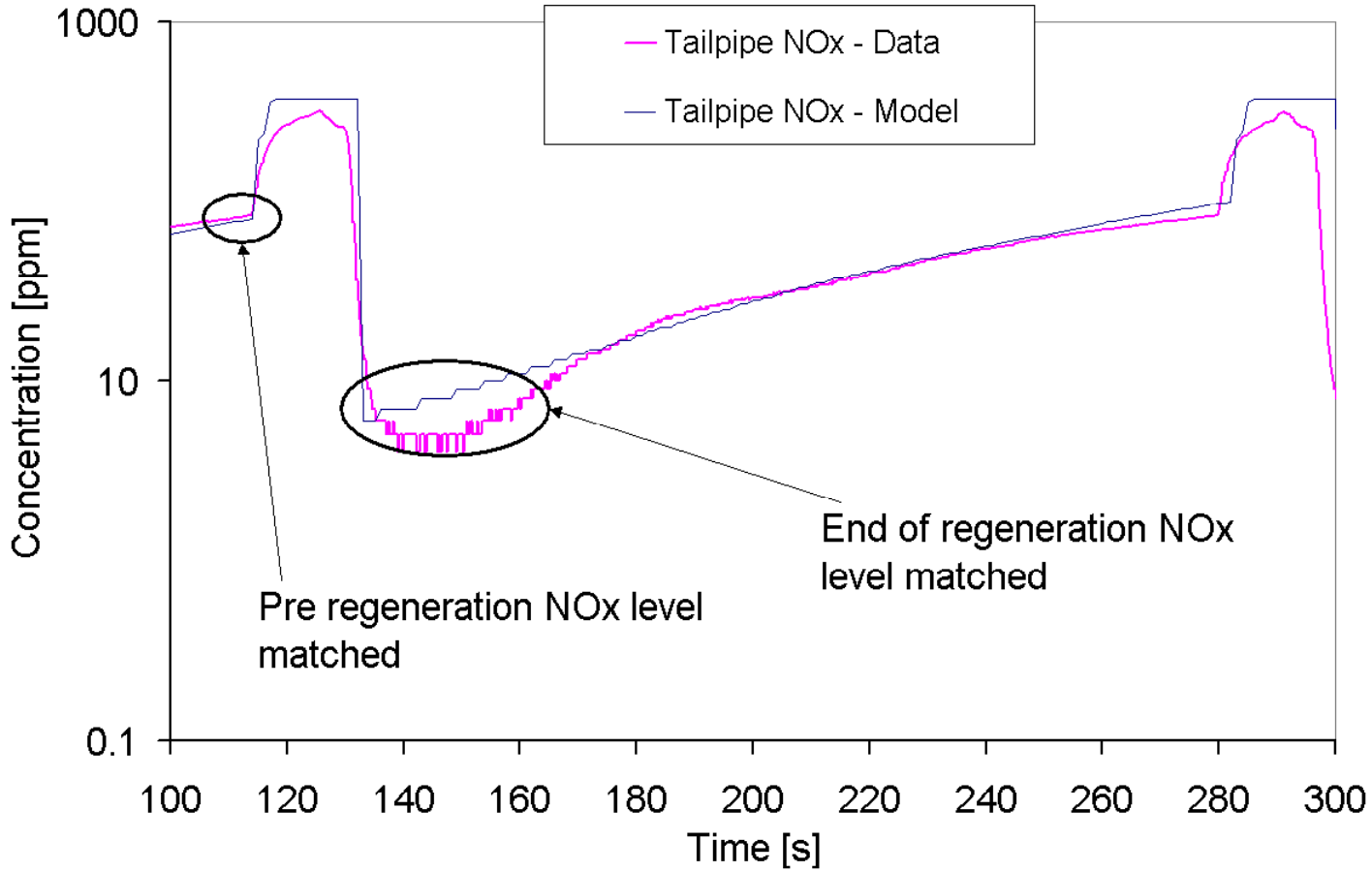




NSR System Modeling Tools

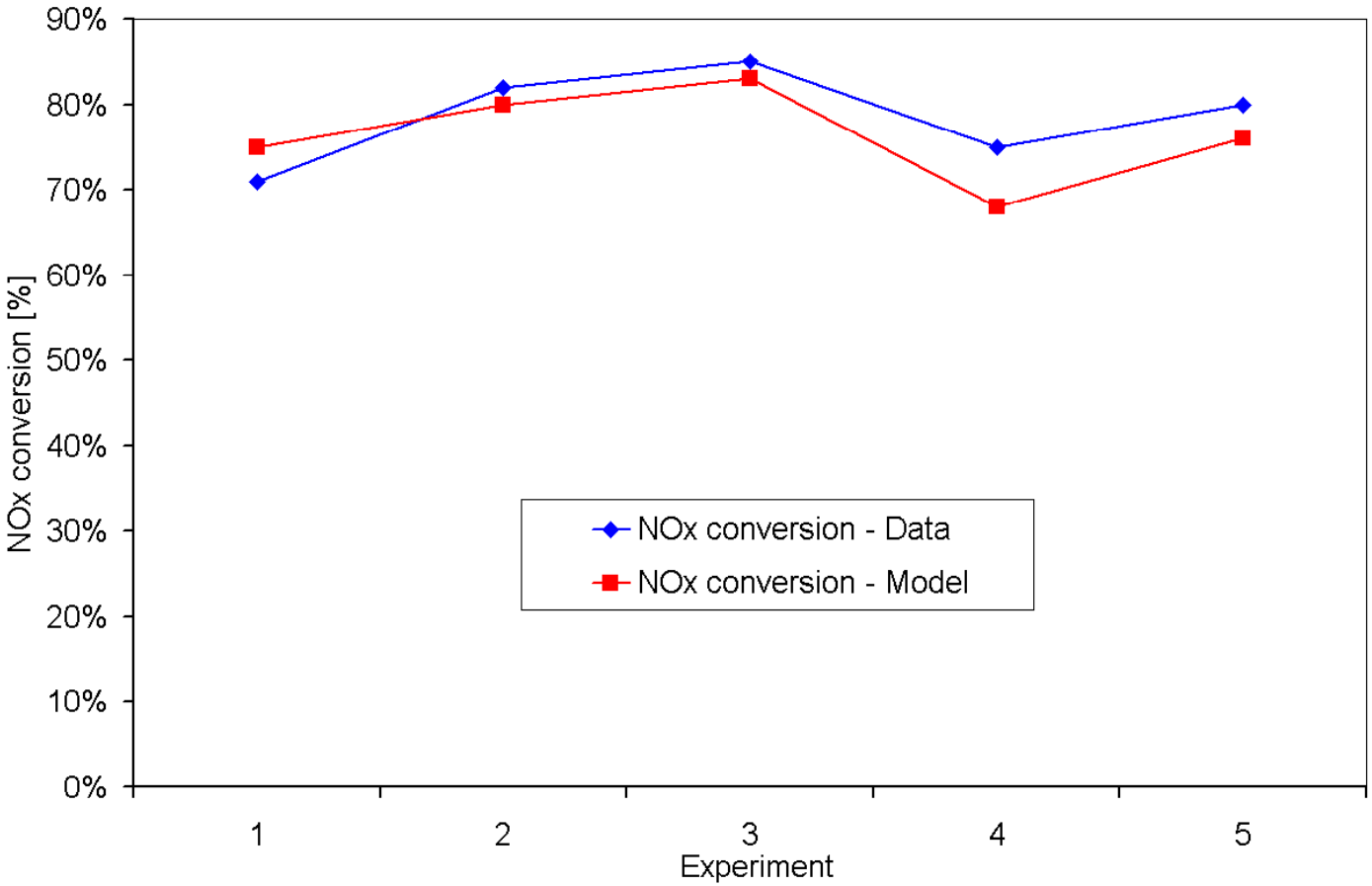


NSR System Modeling Results

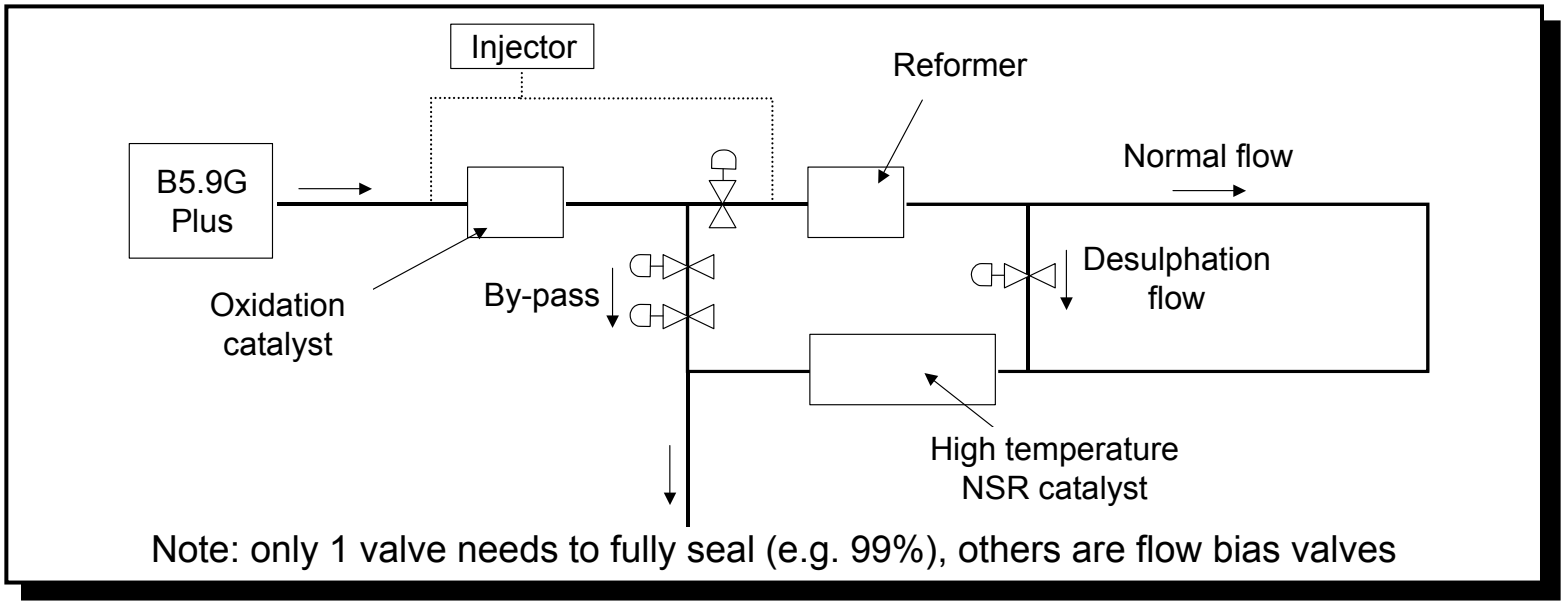


- Results from first system used to calibrate and refine modeling tools

NSR System Modeling Results

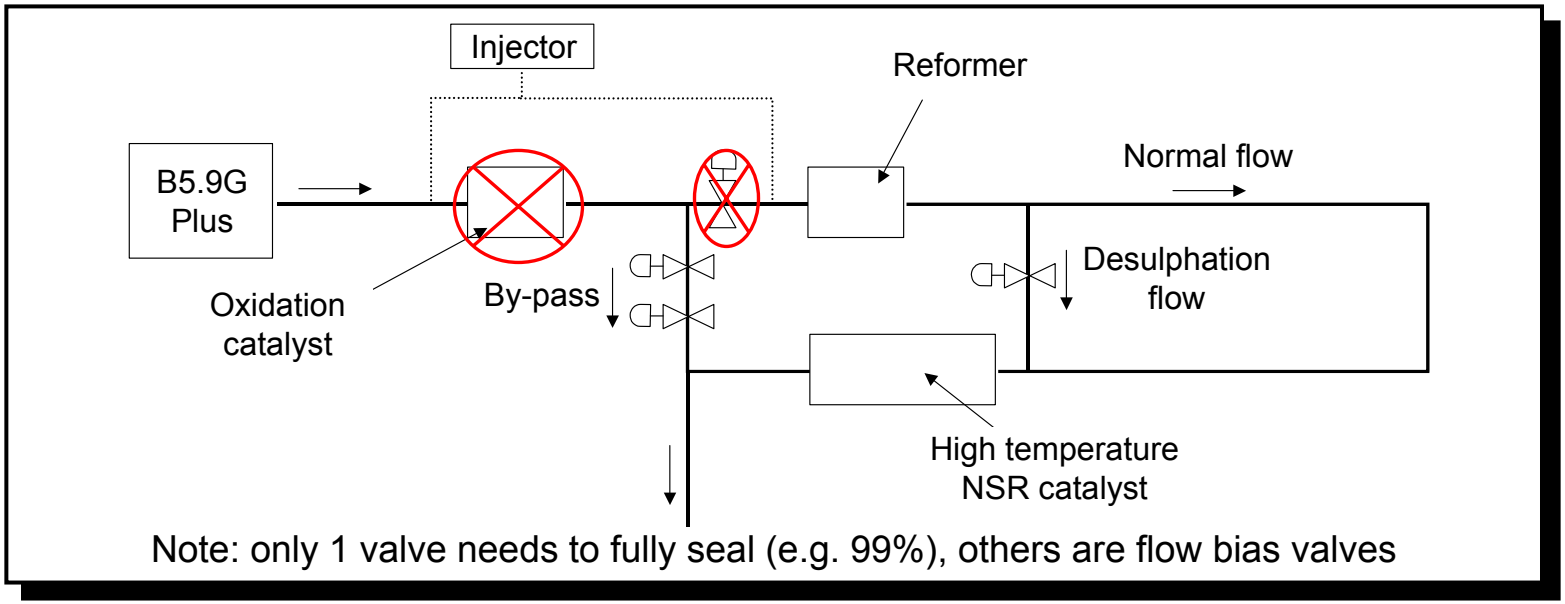


Phase 2 - Refine



- Additional complexity required to promote better regeneration and desulphation across full operating range
- Test program will focus on reducing complexity
  - e.g. remove valves, close coupled catalyst etc.
- Single bed still preferred over dual bed
  - dual bed results can be inferred from this set-up

Phase 2 - Refine



- Refined system now in test cell undergoing development
- Final catalyst confirmation
- Valve setting optimization
- Complexity reduction (removed c/c cat and one valve)
- Control strategy development

Phase 2 - Demonstrate

- Demonstration over AVL 8-mode
  - Trade-off b/w in-cylinder reduction and NSR system reduction to reach 0.5 and 0.2 g/bhp-hr NOx
- On track to meet 0.5g/bhp-hr NOx emission with less than <3% fuel penalty from NSR system

Phase 3 – Long Term Strategy

- Process
  - ✓Combustion technology review
  - ✓Complementary technologies
  - ✓Technology combination
  - – Concept development and ranking
- Investigate lean burn versus stoichiometric with complementary technologies such as hybrid electric vehicles

Combustion Technologies

		Ignition source	Peak BMEP	Peak BTE	Cycle BSNOx	Cycle PM
	Baseline configuration		[bar]	[%]	[g/bhp-hr]	[g/bhp-hr]
1	Lean burn homogeneous	spark	17.5	35	1.0	0.01
2	Lean burn homogeneous	pilot	19	38	1.8	0.05
3	Stoichiometric homogeneous	spark	14	32	6.0	0.01
4a	Stratified (DI)	pilot	25	44	2.2	0.025
4b	Stratified (DI)	pilot	22	40	1.5	0.05
5	Stratified (DI)	glow plug	25	38	2.0	0.02
6	HCCI	-	14	41	0.1	?
	Baseline with EGR					
7a	Lean burn homogeneous	pilot	18	37	1.2	0.05
7b	Lean burn homogeneous	pilot	17	33	0.5	0.05
8	Stoichiometric homogeneous	spark	20	38	1.0	0.01
9a	Stratified (DI)	pilot	22	42	1.2	0.025
9b	Stratified (DI)	pilot	20	40	0.5	0.05
10	Stratified (DI)	glow plug	22	38	1.2	0.02
	VVT (Atkinson/Milller)					
	Miller effect	spark	-1	+3	-	
11	Lean burn homogeneous	spark	16.5	38	1.5	0.01
12	Stoichiometric homogeneous	spark	16.5	36	6.0	0.01

These are now lower

Complementary Technologies

Vehicle/Control and Air Handling

- Hybridization (mild, series, parallel)
- CVT
- Turbo-compounding
- Combustion sensing
- VVT/VVA

Emissions Control

- Lean NOx catalyst
- SCR
- Plasma assisted catalysts
- NSR (1 & 2 bed)
- Three way catalyst
- Wall flow PM filter
- Particle oxidation catalyst

Concept Dev't and Ranking

	LBSI+NSR	SI+EGR+TWC	HPDI+NSR
Conventional	✓	✓	
CVT	✓	✓	
HEV	✓	✓	✓

Ranking process:

- Matlab-Simulink based models in use
  - Emissions Control / Advisor
- Simulation data will be used in ranking process
- Ranking process will include technical and commercial considerations

Summary

- 1.2 g/bhp-hr demonstration calibration is available
- NOx emissions control system is well advanced
- Demonstration on-going
- Long term strategy work is progressing
- Project wrap up and final report scheduled for September